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Case Study on Design and Analysis of Worm Gear Box for Elevator

Divij Pharkute[1], Varad Pimple[2], Piyush Khandekar[3], Akshata Pokharkar[4], Parimal Phanse[5]

[1-5]*Student of Vishwakarma Institute of Technology, Pune, Maharashtra, India*

Abstract - *Elevator is the device which is used to transfer people on different floors in a building, for doing so they use electric motors and worm gear box. A worm gear box consists of a worm gear & worm wheel. The input of the motor is given to the worm gear which in turn drives the worm wheel, to which pulley is attached. Worm gears are most suitable for transmitting power between two shafts that are perpendicular but not intersecting. They are mainly used for this application because of high speed reduction ratio. In this paper, worm gear box is designed for 6 passengers & FEA analysis is doneby applying different forces on worm gear and wheel. Structural was performed in ANSYS software while the Modelling was done on Solidworks.*

***Key Words*: Elevator, worm gear box, high speed reduction, ANSYS, solidworks.**

1. INTRODUCTION

A worm gear (or worm drive) is a specific gear composition in which a screw (worm) meshes with a gear/wheel similar to a spur gear. The set-up allows the user to determine rotational speed and also allows for higher torque to be transmitted. An electric motor or engine applies rotational power via to the worm. The worm rotates against the wheel, and the screw face pushes on the teeth of the wheel. The wheel is pushed against the load. Applications - Lifting Devices, Cranes, Elevators, Belt conveyors etc.

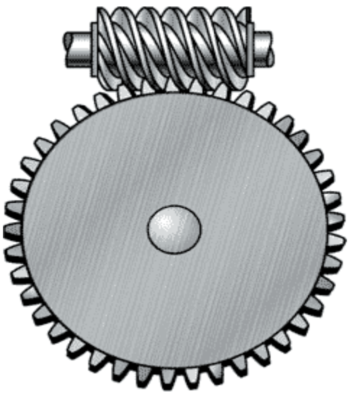


Fig -1: Worm and Worm Wheel

2. THEORY

Application of elevator-

An elevator's function is to convert the initial electrical power, which runs the motor, into mechanical power, which can be used by the system. The elevator is composed of a motor and, most commonly, a worm gear reducer system. A worm gear system is made up of a worm gear, typicallycalled the worm, and a larger round gear, typically called the worm gear. These two gears which have rotational axes perpendicular to each other, not only decrease the rotational speed of the traction pulley, but also change the plane of rotation. By decreasing the rotation speed, with the use of a gear reducer, we are also increasing the output torque, therefore, having the ability to lift larger objects for a given pulley diameter. A worm gear is chosen over other types of gearing possibilities because of its compactness andits ability to withstand higher shock loads. It is also easily attached to the motor shaft, sometimes through use of a coupling. The Figure 1: Worm and Worm Wheel3 gear reduction ratios typically vary between 12:1 and 30:1. The motor component of the elevator machine can be either a DC motor or an AC motor. An AC motor is more regularly used because of its ruggedness and simplicity. A motor is chosen depending on design intent for the elevator. Power required to start the car in motion is equal to the power to overcome static, or stationary friction, and to accelerate the mass from rest tofull speed.

3. METHODOLOGY

Worm & worm gear Terminology A pair of Worm & worm gear is specified & designated as –

z1/ z2/q/m

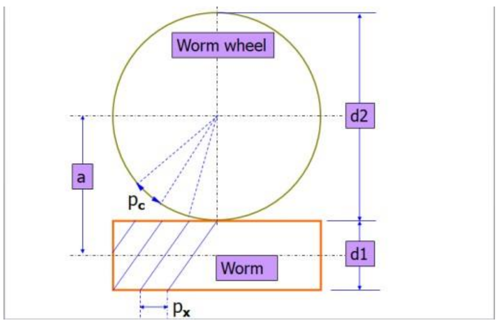


Fig -2: Terminology of Worm and Worm Whee

Where,

z_1 = no. of start on worm

z_2 = no. of teeth on worm wheel

q = diametral quotient =d1/m m

= module

Axial Pitch - **(p_x)** defined as distance between two consecutive teeth measured along the axis of worm.

Lead **(l) –** It is defined as distance that a point on helical profile will move in axial direction when worm is rotated through one revolution.

$$\mathbf{l} = p_x * z_1$$

Circular Pitch - **(p_c)** defined as distance measured along pitch circle from one point on one tooth to the corresponding point on adjacent tooth.

Lead angle of worm **(γ) -** When one thread of worm is developed it becomes hypotenuse of the triangle. Thebase of triangle is equal to circumference of worm & altitude is equal to lead of worm.

$$\tan\gamma = \frac{z_1}{q}$$

ha1- Addendum of worm (mm)

hf1- Dedendum of worm (mm)

c- Clearance of worm (mm)

ha2- Addendum at the throat of worm wheel (mm)

hf2- Dedendum in the median plane of worm wheel (mm)

lr- Length of root of worm wheel teeth (mm)

v_s- Rubbing velocity (m/s)

d_1 - diameter of worm

d_2 – diameter of worm wheel

4. CALCULATIONS

The elevator was designed for the capacity of 6 people so as to transfer people on different floors. It takes the input power from the motor which is given to worm gear box so as to reduce the speed to the required level and torque.

Input parameters-

No. of Passengers = 6

Average Weight = 70 kg

Lift speed (v) =1 m/s

Motor (N) (rpm) = 960 [3]

Pulley diameter (d) =0.53 m

Duty (weight on lift) =420 kg

Weight of the car =1000 kg

Total weight (W_1) =1000 + 420

=1420 kg (13930.2 N)

Dead weight (W_2) =Duty/2 + (weight of car) [4]

=420/2 + 1000

= 1210 kg (11870.1 N)

Materials-

Worm = Case hardened steel

Worm wheel = Phosphor bronze

Output parameters-

Torque (T) = (W_1-W_2)*r

= (13930.2 - 11870.1)* 0.53 /2

=**545.9265 N-m**

$$v = \frac{\pi * d * n}{60}$$

$$n = \frac{60*1}{\pi * 0.53}$$

=**36 rpm**

Power output,

$$P_{out} = \frac{2*\pi*n*T}{60}$$

$$= \frac{2*\pi*36*545.9265}{60}$$

= **2060.1 w**

Gear box,

Speed reduction (i) = $\frac{N}{n} = \frac{960}{36}$ =26.67

Therefore, the nearest standard gear ratio is

= 25

Now taking new gear ratio,

$$25 = \frac{960}{n}$$

$$n = \frac{960}{25}$$

$$n = 38.4$$

New lift speed,

$$v = \frac{\pi*d*n}{60}$$

$$= \frac{\pi*0.53*38.4}{60}$$

$= 1.07$ **m/s**

According to the value of speed reduction (i) the values of z_1& z_2 are as follows-

No. of start on worm (z_1) = 1

No. of teeth on worm wheel (z_2) = 25

Assuming value of diametral quotient (q) as 10

Therefore,

(z_1) = 1

(z_2) = 25

(q) = 10

Lead angle (γ),

$$\tan(\gamma) = \frac{z_1}{q}$$

$$\tan(\gamma) = \frac{1}{10}$$

$$(\gamma) = 5.71$$

$= 0.099669$ **radians**

Diameter of worm gear (d_1),

$d_1 = q*m$

= **10*m**

Diameter of worm wheel (d_2),

$d_2 = z_2*m$

= **25*m**

Velocity of worm (v_g) or (v1)

$$v_g = \frac{\pi*d_1*N}{60}$$

$$v_g = \frac{\pi*q*m*960}{60}$$

$v_g = 502.4*m$ **mm/s**

Velocity of worm wheel (v_w) or (v2)

$$v_w = \frac{\pi*d_2*n}{60}$$

$$v_w = \frac{\pi*25*m*38.4}{60}$$

$v_w = 50.24 * m$ mm/s

Sliding velocity (v_s),

$$V_s = \frac{V_1}{\cos\gamma}$$

$v_s = 0.505 * m$ m/s

Effective Face width of worm wheel (F),

$$F = 2 * m * \sqrt{q+1}$$

$$F = 2 * m * \sqrt{11}$$

$F = 6.633$ *m

Outside diameter of worm (da_1),

$$da_1 = m*(q+2)$$

$$= m*(10+2)$$

$$= 12 * m$$

Clearance(c),

$$= 0.2 * m * Cos\gamma$$

$$= 0.2 * m * Cos(5.71)$$

$$= 0.2 * m$$

Length of root of worm wheel (l_r),

$$l_r = (d_{a1} + 2c) * Sin^{-1}\left(\frac{\Box F}{d_{a1} + 2c}\right)$$

$$= 7 * m$$

Worm gearing design as per IS-7443-1974

Based on beam strength.

$$M_{t1} = 17.65 * X_{b1} * S_{b1} * m * l_r * d_2 * Cos\gamma \quad N.mm$$
$$M_{t2} = 17.65 * X_{b2} * S_{b2} * m * l_r * d_2 * Cos\gamma \quad N.mm$$

M_{t1} or M_{t2} = *Permissible torque on worm wheel N.mm*

X_{b1} or X_{b2} = *Speed factor for strength of worm & worm wheel*

S_{b1} or S_{b2} = *Bending stress factor for worm & worm wheel*

l_r = *Length of the root of worm wheel tooth(mm)*

Fig -3: Based on Beam Strength Terminology

Values of Xb_1, Xb_2, Sb_1 & Sb_2 are taken from standard graphs and tables.

Xb_1=0.255

Xb_2=0.4875

Sb_1=28.2

Sb_2=7

Now,

$$Mt_1 = 17.65 * Xb_1 * Sb_1 * m * lr * d_2 * \cos(\gamma)$$

545.9265 = 17.65*0.255*0.28*m*7*m*cos(5.71)

m = 2.90

$$Mt_2 = 17.65 * Xb_2 * Sb_2 * m * lr * d_2 * \cos(\gamma)$$

545.9265 = 17.65*0.4875*7*m*7*m*cos(5.71)

m = 3.72

Based on wear strength.

$$M_{t3}=18.64*X_{c1}*S_{c1}*Y_z*(d_2)^{1.8}*m$$
$$M_{t4}=18.64*X_{c2}*S_{c2}*Y_z*(d_2)^{1.8}*m$$

M_{t3} or M_{t4} = *Permissible torque on worm wheel N.mm*

X_{c1} or X_{c2} = *Speed factor for wear of worm & worm wheel*

S_{c1} or S_{c2} = *Surface stress factor for worm & worm wheel*

Y_z = *Zone factor*

Fig 4 -: Based on Wear Strength Terminology

Values of Xc_1, Xc_2, Sc_1 & Sc_2 &Yz are taken from standard graphs and tables.

Xc_1=0.18

Xc_2=0.4125

Sc_1=4.93 Sc_2=1.55

Yz=1.143

Thus,

$$M_{t3} = 18.64*X_{c1}*S_{c1}*Y_z*(d_2)^{1.8}*m$$

545.9265 = 18.64*0.18*4.93*1.143*$(25*m)^{1.8}$*m

m = 4.94

$$M_{t4} = 18.64*X_{c2}*S_{c2}*Y_z*(d_2)^{1.8}*m$$

545.9265 =18.64*0.4125*1.55*1.143*$(25*m)^{1.8}$*m

m = 5.56

Therefore, the highest value of m among the above four equations is,

m = 5.56

Therefore,

The new sliding velocity is-

$$v_s = 0.505*m$$

= 0.505*5.56

= 2.20 m/s

The new values of Xc1, Xc2, according to the sliding velocity are as follows-

Xc_1=0.135

Xc_2=0.2995

$$Mt_{3(1)} = 18.64*Xc_1*Sc_1*Yz*(d_2)^{1.8}*m$$

=18.64*0.135*4.93*1.143*$(25*m)^{1.8}$*m

m = 5.48

$$Mt_{4(1)} = 18.64*Xc_2*Sc_2*Yz*(d_2)^{1.8}*m$$

=18.64*0.2995*1.55*1.143*$(25*m)^{1.8}$*m

m = 6.23

Thus, the highest value of m is 6.23 & the standard worm gear available for the same is-

z_1/ z_2/q/m

1/25/6.5/8

5. SOLVER/CODE

This code is made in excel with same input parameters as above & the output of the solver is the value for the worm gear box.

No. of Passengers	6			
Average Weight	70	Kg		
Duty	420	Kg		
Weight of Car	1000	Kg		
Total Weight	1420	Kg	13930.2	N
Counter Weight	1210	Kg	11870.1	N
Rated Speed	1	m/s		
Drum Diameter	530	mm	0.53	m
Motor to be used(RPM)	960	rpm		
Material For Worm	Case Hardened Steel			
Material For Worm Wheel	Phosphour Bronze			
Basic Output Parameters				
Torque at Pulley	545.9265	N-m		
Output RPM at pulley and worm wheel (linear velocity to angular)	36.05336	rpm		
Output Power	2060.1	W		

Fig 5 -: Excel Solver 1/6

Gear Box Design			
Speed Reduction(i)=		26.6272	
Nearest Standard Gear Ration		25	
Assume No. of Starts on Worm(Z1)		1	
So, No. of teeth on Worm Wheel (Z2)		25	
i(modified)		25	
Output Speed(modified)		38.4	rpm
Changed Velocity of Elevator		1.065088	m/s
Assumption for Furthur Design			
Assume q=		10	
Lead Angle		0.099669	radians
Velocity of worm wheel	m*	50.24	mm/s
Velocity of worm	m*	502.4	mm/s
Sliding Velocity	m*	504.9058	mm/s
	m*	0.504906	m/s

Fig 6 -: Excel Solver 2/6

Beam Strength Considerations			
Inputs			
Xb1	0.255		
Sb1	28.2		
Ir			
Xb2	0.4875		
Sb2	7		
Yz	1.143		
Effective face width worm wheel(F)	6.633	*m	mm
Addendum Diameter(da1)	12	*m	mm
Cl (hf-ha)	0.2	*m	mm
Ir	7	*m	mm
Wear Strength Considerations			
Inputs			
Xc1	0.18		
Xc2	0.4125		
Sc1	4.93		
Sc2	1.55		
Yz	1.143		

Fig 7 -: Excel Solver 3/6

Calculating m by the formulas of Mt1 and Mt2	
By Mt1	
m	2.907507
By Mt2	
m	3.727574
Calculating m by the formulas of Mt1 and Mt2	
By Mt3	
m	4.947298
by Mt4	
m	5.56176

Fig 8 -: Excel Solver 4/6

So, highest value of m is	5.56176	
Calculating modified sliding velocity	2.808165	m/s
Coefficient of Friction(μ)	0.02875	
μv	0.028893	
ϕv	0.028885	radians
	1.655848	degree
Again Calculating m by wear strength formulas		
Inputs		
Xc1	0.135	
Xc2	0.2995	
By Mt3		
m	5.482631	
by Mt4		
m	6.235407	

Fig 9 -: Excel Solver 5/6

So, the standard worm gear box available is	
Z1	1
Z2	25
q	6.5
m	8

Fig 10 -: Excel Solver 6/6

The following is the code in python for obtaining the different parameters of worm wheel & gear for the gear box.

```
py > msd lab 1.py > ...
import math
z1= int(input("No. of Starts on worm(z1)="))
z2= int(input("No. of teeth on worm wheel(z2)="))
q= float(input("Diametral Quotient(q)="))
m=int(input("Module(m) in mm="))

d1= q*m
d2= m*z2
px= (math.pi*d2)/z2
lead= px*z1

gamma= (math.atan(z1/q))
da1= m*(q+2)
df1= m*(q+2-(4.4*math.cos(gamma)))
da2= m*(z2+(4*math.cos(gamma))-2)
df2= m*(z2-2-(0.4*math.cos(gamma)))
f= (2*m * ((q+1)**(1/2)))
c= (0.2*m)*math.cos(gamma)
delta= math.asin(f/(da1+(2*c)))
lr=(da1+2*c)*delta
a=(d1+d2)*0.5
i=(z2/z1)
helixangle= (math.pi/2)-gamma

print("\n")
print("Lead(l)=",lead, "mm")
print("Lead Angle(gamma)=",gamma, "radians")
print("\n")
print("Worm Dimensions")
print("\n")
print("Pitch Circle Diameter of Worm(d1)=",d1,"mm")
print("Axial Pitch of Worm(px)=",px,"mm")
print("Outside Diameter of Worm(da1)=", da1, "mm")
print("Root Diameter of Worm(df1)=", df1,"mm")
print("\n")
print("Worm Wheel Dimensions")
print("\n")
print("Pitch Circle Diameter of Worm Wheel(d2)",d2,"mm")
print("Throat Diameter of Worm Wheel(da2)=",da2,"mm")
print("Root Diameter of Worm Wheel(df2)=",df2,"mm")
print("Effective Face Width(f)=",f,"mm")
print("Length of root of Worm Wheel teetth(lr)=",lr,"mm")
print("\n")
print("Center Distance(a)=",a, "mm")
print("Speed Reduction(i)=",i)
print("Helix Angle=",helixangle,"radians")
```

Fig 11 -: Python Code

```
Terminal  Help                msd lab 1.py - c: - Visual Studio Code
PROBLEMS  OUTPUT  DEBUG CONSOLE  TERMINAL

PS C:\> python -u "c:\py\msd lab 1.py"
No. of Starts on worm(z1)=1
No. of teeth on worm wheel(z2)=25
Diametral Quotient(q)=6.5
Module(m) in mm=8

Lead(l)= 25.132741228718345 mm
Lead Angle(gamma)= 0.15264932839526515 radians

Worm Dimensions

Pitch Circle Diameter of Worm(d1)= 52.0 mm
Axial Pitch of Worm(px)= 25.132741228718345 mm
Outside Diameter of Worm(da1)= 68.0 mm
Root Diameter of Worm(df1)= 33.20931624269827 mm

Worm Wheel Dimensions

Pitch Circle Diameter of Worm Wheel(d2) 200 mm
Throat Diameter of Worm Wheel(da2)= 215.62789432481975 mm
Root Diameter of Worm Wheel(df2)= 180.837210567518 mm
Effective Face Width(f)= 43.81780460041329 mm
Length of root of Worm Wheel teetth(lr)= 47.204077194617945 mm

Center Distance(a)= 126.0 mm
Speed Reduction(i)= 25.0
Helix Angle= 1.4181469983996313 radians
PS C:\>
```

Fig 12 -: Python Code Output

6. CAD MODEL

With the dimension mentioned in the table 1, following model is made in Solidworks.

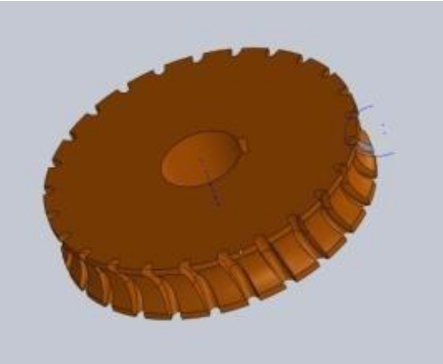


Fig 14 -: Worm Wheel

Table -1: Calculated Dimensions for CAD-Model

No of start on worm	z_1	**1**
No of teeth on worm wheel	Z_2	**25**
Diametral quotient	q	**6.5**
Module	m	**8**
Lead Angle	γ	**8.73**
Worm dimensions		
Pitch Circle Diameter of Worm	d_1	**52 mm**
Axial Pitch of Worm	px	**25.13 mm**
Outside Diameter of Worm	da_1	**68 mm**
Root Diameter of Worm	df_1	**38.2 mm**
Worm wheel dimensions		
Pitch Circle Diameter of Worm Wheel	d_2	**200 mm**
Throat Diameter of Worm Wheel	da_2	**215.62 mm**
Root Diameter of Worm Wheel	df_2	**180.83 mm**
Effective Face Width	f	**43.81 mm**
Length of root of Worm Wheel teeth	lr	**47.2 mm**
Center distance	a	**125 mm**
Speed Reduction	i	**25**

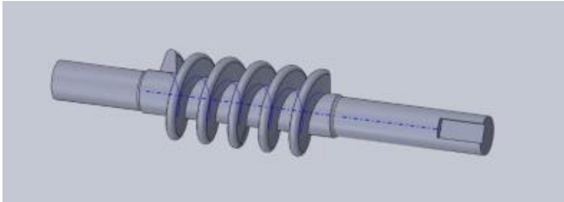


Fig 15 -: Worm

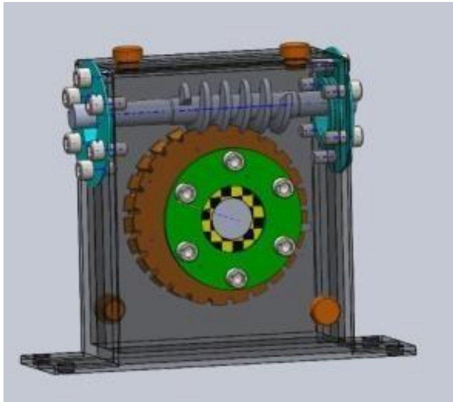


Fig 16 -: Assembly 1/3

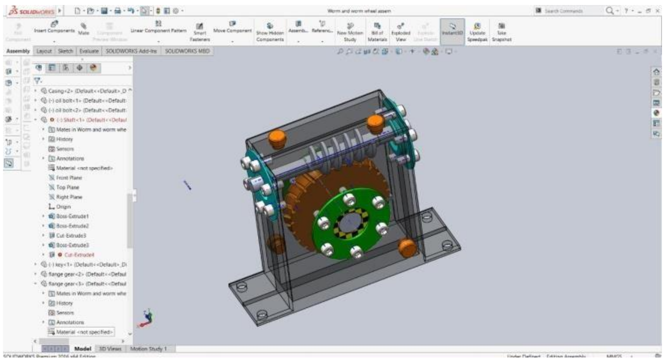


Fig 17 -: Assembly 2/3

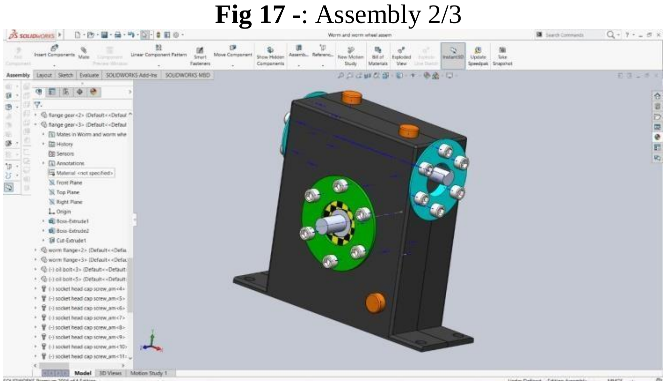
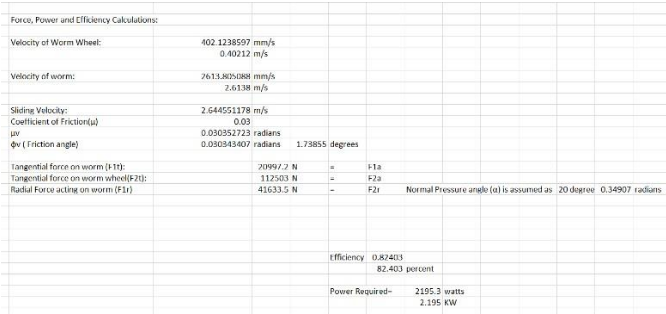


Fig 18 -: Assembly 3/3

7. STRUCTURAL ANALYSIS

Finite Element Analysis was done to ensure that the designed worm gear and worm wheel are in the specified limits.

1) Following excel sheet shows forces acting on a worm and worm gear.



Force, Power and Efficiency Calculations:								
Velocity of Worm Wheel:	402.1238597	mm/s						
	0.40212	m/s						
Velocity of worm:	2613.805088	mm/s						
	2.6138	m/s						
Sliding Velocity:	2.644551178	m/s						
Coefficient of Friction(μ)	0.03							
μv	0.030352723	radians						
φv (Friction angle)	0.030343407	radians	1.73855	degrees				
Tangential force on worm (F1t):		20997.2 N	=	F1a				
Tangential force on worm wheel(F2t):		112503 N	=	F2a				
Radial Force acting on worm (F1r)		41633.5 N	=	F2r	Normal Pressure angle (α) is assumed as	20 degree	0.34907	radians
			Efficiency	0.82403				
				82.403	percent			
			Power Required–	2195.3	watts			
				2.195	KW			

Fig 19 -: Forces Acting on Worm Wheel

2) Maximum deformation obtained is 0.14269 mm on worm gear.

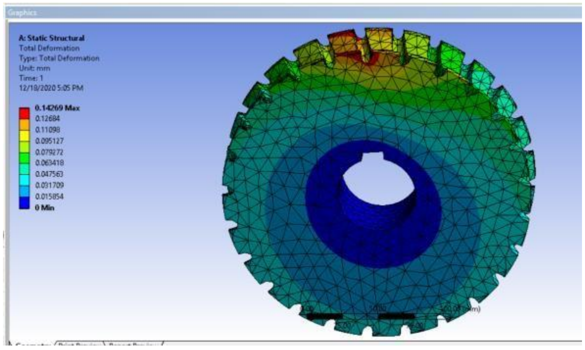


Fig 20 -: Analysis of Worm Gear

3) Maximum deformation obtained is 0.36428 mm on worm.

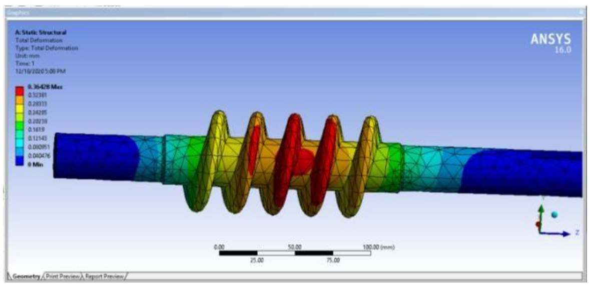


Fig 21 -: Analysis of Worm

8. CONCLUSION

In this paper, the application took for designing the worm gear box is Elevator, where the worm gear box is used. According to the input parameters, the design is done by IS-7443-1974. Then a cad model is made in Solidworks. According to the forces calculated, structural analysis is done on worm gear and worm and deflection of the same found are, 0.14269 mm and 0.36428 mm respectively.

REFERENCES

[1] V. B. Bhandari. "Design of Machine Elements", Third Edition.

[2] V. B. Bhandari, "Machine design data book".

[3] Design, Fabrication, Supply, Installation & Commissioning of Passenger Lift for ITMT Building, Indian Institute of Astrophysics, Bangalore, 2017

[4] TECHNICAL SPECIFICATIONS FOR ELEVATORS (6 PASSENGERS), Kerala Government.